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Efficiency Enhancement of M2M Communications over LTE using Adaptive Load Pull Techniques

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Abstract—Long Term Evolution (LTE) communications systems are increasingly used for remote applications where a battery life of at least ten years is often required. Numerous technologies have been proposed to increase the efficiency of this standard, particularly the power amplifier, however these tend to involve resource intensive signal processing, together with a higher component count. This paper presents the use of a low speed load pull technique, with and without a dynamic power supply system in order to optimise performance. This system was tested with LTE signals and appropriate hardware, providing up to 44% increase in power-added efficiency for the fixed supply voltage case and a 27% increase over basic dynamic power supply architectures whilst maintaining ACLR and EVM performance.

Index Terms—Power amplifiers, load modulation, average efficiency, machine-to-machine communications, 4G Mobile communication .

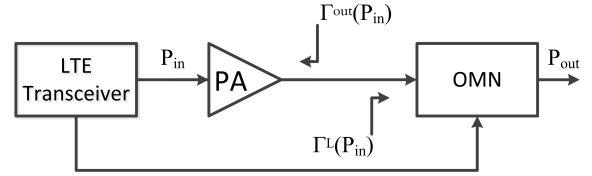
I. INTRODUCTION

The number of connected devices is predicted to increase exponentially over the next few years. Of particular interest is the use of machine to machine (M2M) communications. M2M communications can cover a vast array of data types and transmission durations, however of particular interest to this paper is the case of wireless sensor networks, which are likely to be remote and battery powered. Consumers have been demanding battery lives of at least ten years, which puts intense demand on modem efficiency. The power amplifier and associated components tend to be the most power hungry blocks in the communications system, and thus become prime targets for efficiency enhancement technologies.

There already exists a large range of technologies aimed at increasing PA efficiency, generally modulating supply, as in envelope tracking [1], [2] or load modulation schemes [3], [4], however these can be complex to implement and expensive in terms of component count. Similarly, lower frequency dynamic power supply (DPS) systems can be employed, albeit with less improvement in performance. Here an alternative method of adaptive load pull, together with supply voltage modulation, is proposed. Similar work has been done in [5], however with wideband signals and

still with the need for additional control signal generation and feedback. This system uses MAC layer information for its operation, removing the need for feedback or high speed analogue to digital converters (ADCs) for sampling and control.

(a)



(b)

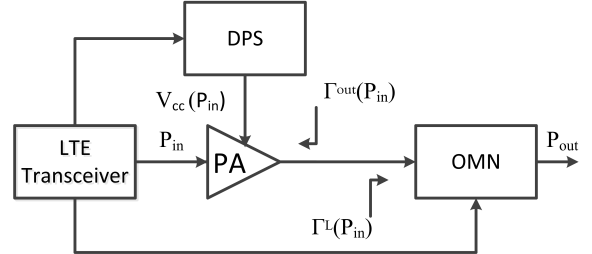


Fig. 1. Block diagram of proposed schemes; (a) - load pull, (b) - load pull and DPS

II. THEORY

LTE lends itself to a wide variety of uses due to the highly adaptive nature of the bandwidth, modulation scheme and power output. One of the main advantages of an adaptive link budget, is that due to the use of pilot signals and closed loop power control, the RFIC has knowledge of the power required to be transmitted to a base station, and thus, the amount of power passed into the PA.

LTE power levels are typically updated aperiodically depending on a number of variables, however as they are dependant on the Physical Downlink Control Channel

(PDCCH) signals, which are updated not more often than each subframe, this will not change more than once every millisecond [6]. Low rate DPS systems have previously been used to good effect in [7], however DPS bandwidth is still high, and requires intensive processing of the baseband signal. Modulating the power supply in the kHz range rather than MHz territory will limit maximum Power Added Efficiency (PAE), however the system will require a minimum of external circuitry, and will also be able to make use of lower bandwidth, more efficient power supplies.

Most power amplifiers units destined for user equipment (UE) are optimised to be well matched at maximum output power, however this means there are considerable gains to be made when the amplifiers is operating below this level, and is thus able to be presented with load that will enable more optimal operation for a particular output power level. Figure 1 (a) shows the basic system, where a variable Output Matching Network (OMN) is used to vary reflection coefficient as a function of input power, provided by knowledge of the LTE MAC layer. Figure 1 (b) shows a further refinement, where in addition to optimising the output match, the transceiver is also able to control supply voltage as a function of input power.

III. MEASUREMENT SET-UP, RESULTS AND DISCUSSION

A. Measurement Set-up

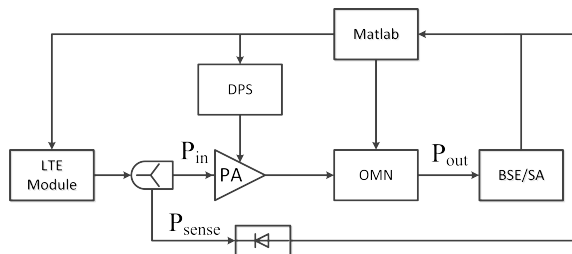


Fig. 2. Block diagram of measurement setup

To demonstrate the feasibility of these techniques, a hardware-in-the-loop setup was used, using a backed-off ublox Toby L210 LTE modem to generate a test signal, an external power amplifier, appropriately instrumented, and a combination base station emulator (BSE) / spectrum analyser (SA) to facilitate communication and measure performance. The external amplifier used as the device under test (DUT) was the Skyworks SKY77765 Gallium Arsenide (GaAs) microwave monolithic integrated circuit (MMIC)

Base performance was established by running an input power sweep of the PA, measuring input & output RF power along with DC power consumed in order to calculate PAE. The test signal used was an LTE uplink signal of 1.4 MHz bandwidth centred at 881 MHz (Band V),

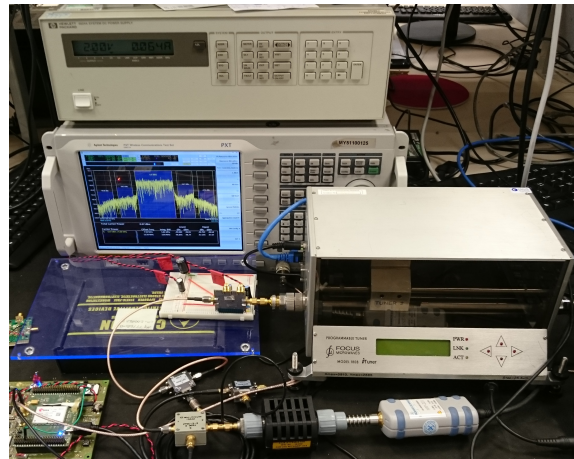


Fig. 3. Photograph of measurement setup

transporting pseudo-random data. Figure 2 illustrates this test setup and shows the flow of control data from a MATLAB script, together with sensor data passed back for analysis.

In order to evaluate the effects of load modulation, a mechanical tuner was used to sweep various trajectories on a Smith Chart. The tuner response was swept for each of a range of input power levels until optimum PAE was achieved. This technique was then repeated using a supply voltage proportional to the output power required. To obtain a baseline result, an input power sweep was completed. At each step PA supply voltage was reduced until adjacent channel leakage ratio increased in excess of -40dBc, a level chosen to exceed LTE UE specifications. PAE was then measured at this point. Similarly to the first experiment, a load pull sweep was then enacted in order to gauge the effectiveness of these techniques combined. It is important to note that ACLR and EVM performance were monitored during the tests, and any optimum PAE results were discarded if they would not have passed LTE UE requirements.

B. Results

Regarding the fixed supply voltage operation in Figure 4, improvements in performance are generally small at lower output power levels, however significant improvement can be obtained from 15dBm onwards. The 15-25dBm region shows an increase of up to 44% in PAE, with both the standard and optimised traces beginning to converge at peak power, suggesting the amplifier was optimally matched for this level.

The two other traces in figure 4 compare PAE for a supply voltage modulation as per subsection III-A, both with and without adaptive load modulation. It can be seen that the largest improvements of the load pull are based around the 10-25 dBm region, with a maximum of 27% increase in efficiency. Slight variation in the trend of the

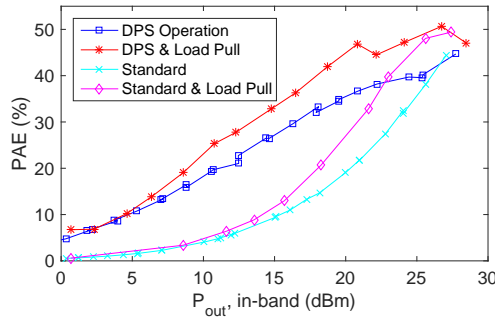


Fig. 4. Amplifier PAE for an output power sweep

load pull trace are likely to indicate that the granularity of the tuner setting was not sufficiently small to be able to achieve the optimum result.

Figure 5 shows the S_{11} values provided by the tuner over the ranges of optimum operation. The area of the smith chart covered is reasonably small, suggesting there is a large scope for a range of minaturisable technologies that could accomplish similar trajectories.

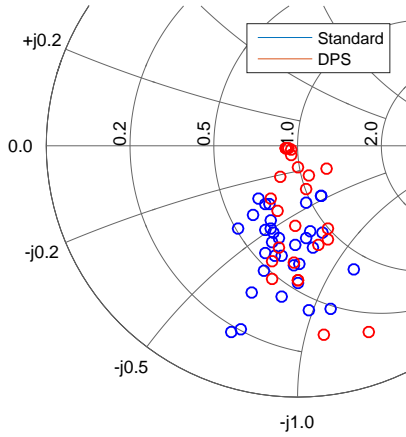


Fig. 5. Smith chart coverage for standard and DPS load pull.

C. Discussion

It can be seen from the results that significant increases in PAE can be achieved using low speed techniques governed by information obtained only from the LTE MAC layer, removing the need for any additional signal sampling and processing during operation. Additionally, lower modulation of supply voltage and load allow a wider range of candidate technologies to be employed to fulfil this function. Figure 5 shows the S_{11} provided by the tuner for both cases.

It is important to note that although the biggest improvements in PAE were not at peak power, the output power at

which a device operates at will be based largely on location and environment. It is highly likely that the middle of the operating power range will be most utilised over a range of scenarios and thus will obtain the most benefit.

There are of course limitations to the experimental setup; The response of amplifier PAE for a single input power level, over a range of tuner settings exhibited many sharp peaks. Peak PAE often appeared as a single outlier, suggesting that the tuner step size could be reduced in order to further improve results by presenting optimum S_{11} .

One of the main considerations for LTE user equipment is miniaturisation. Further work will focus on the ability to cover similar areas of the Smith chart with techniques such as matching networks incorporating varactor tuning diodes and MEMS capacitors.

IV. CONCLUSION

A technique for enhancing the power-added efficiency of an LTE amplifier was presented, this required no more sampling of the LTE signal than would normally be available at the MAC layer of the RFIC, leading to a reduced component cost. Since the average RF channel power is updated at a maximum sub kHz rate, simpler power supply and output tuning may be employed with ease in order to realise these benefits. It is believed that these techniques may also be employed in future communications systems using similar power control methods.

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